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Comparison of radiocesium concentration changes in leguminous and non-leguminous herbaceous plants observed after the Fukushima Dai-ichi Nuclear Power Plant accident

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A B S T R A C T

Transfer of radiocesium from soil to crops is an important pathway for human intake. In the period from one to two years after the Fukushima Daiichi Nuclear Power Plant (FDNPP) accident, food monitoring results showed that radiocesium concentrations in soybean (a legume) were higher than those in other annual agricultural crops; in these crops, root uptake is the major pathway of radiocesium from soil to plant. However, it was not clear whether or not leguminous and non-leguminous herbaceous plants have different Cs uptake abilities from the same soil because crop sample collection fields were different. In this study, therefore, we compared the concentrations of ^{137}Cs in seven herbaceous plant species including two leguminous plants (*Trifolium pratense* L. and *Vicia sativa* L.) collected in 2012–2016 from the same sampling field in Chiba, Japan that had been affected by the FDNPP accident fallout. Among these species, *Petasites japonicus* (Siebold & Zucc.) Maxim. showed the highest ^{137}Cs concentration in 2012–2016. The correlation factor between all concentration data for ^{137}Cs and those for ^{40}K in these seven plants was $R = 0.54$ ($p < 0.001$) by *t*-test, thus potassium uptake ability by species would affect radiocesium uptake; however, for each species, no correlation between ^{137}Cs and ^{40}K was found. Interestingly, ^{40}K concentrations in *T. pratense*, *V. sativa* and Poaceae family plants did not differ significantly, but ^{137}Cs data in the Poaceae family plants were significantly lower than those in *T. pratense* ($p < 0.001$) and *V. sativa* ($p = 0.017$). The results indicated that leguminous species would have higher ^{137}Cs uptake ability than Poaceae family plants.

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1. Introduction

The Fukushima Daiichi Nuclear Power Plant (FDNPP) accident discharged massive amounts of radionuclides to the environment. Since then, extensive food monitoring has been carried out to check the radiocesium (^{134}Cs+^{137}Cs) contents in foods in order to avoid eating contaminated food items exceeding food standard limits applied in Japan (>100 Bq kg^{-1} fresh weight) (Ministry of Health, Labour and Welfare, 2017). More than one year after the FDNPP accident, because atmospheric releases had become negligible, the major radiocesium transfer pathway to annual agricultural crops became root uptake. From food monitoring results, Hirayama et al. (2015) observed that the radiocesium concentrations in soybean samples tended to be higher than those in brown rice and other grain species. Outside Japan, similarly, a greenhouse experiment showed that ^{137}Cs concentrations in soybean beans were higher than those in wheat grains (Adriano et al., 1984).

Interestingly, however, in the Technical Report Series No. 472 by the IAEA (2010), similar soil-to-crop transfer factor (TF = concentration in crop [Bq kg^{-1}-dry]/concentration in soil [Bq kg^{-1}-dry], dimensionless) values were listed for leguminous vegetables (seeds and pods, geometric mean TF $= 4.0 \times 10^{-2}$) and cereals (grains, geometric mean TF $= 2.9 \times 10^{-2}$), but the geometric mean TF for rice grains was lower (8.3×10^{-3}) than those values. TF values for leguimnous fodder (stems and shoots, geometric mean $= 1.6 \times 10^{-1}$) and pasture (stems and shoots, geometric mean $= 2.5 \times 10^{-1}$) were similar in the same literature (IAEA, 2010). Belli et al. (1995), however, reported ^{137}Cs concentrations in grass fodder were higher than those in leguminous fodder. For a case observed after the FDNPP accident, Ohse et al. (2015) reported that

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TF values of ^{137}Cs for rice and green soybean parts in a contaminated field experiment were similar but those observed in a decontaminated field were different; TFs for green soybean parts were higher than those for rice parts.

We did a further data survey using the Environmental Radiation Database compiled by the Nuclear Regulation Authority (2017) and giving data before the FDNPP accident. Global fallout ^{137}Cs concentrations in brown rice (*Oryza sativa* subsp. *japonica* Kato) and adzuki bean (*Vigna angularis* (Willd.) Ohwi & Ohashi) collected in the same local government area in Hokkaido or Kyoto from 1990 to 2010 were summarized in Fig. 1 (all ^{137}Cs data were decay-corrected to January 1, 2010). For the case in Hokkaido, ^{137}Cs concentrations in grains of these two species were significantly different by *t*-test, however, in Kyoto, no difference was found. From these literature survey results, it was unclear whether cesium take-up ability by leguminous plants was higher than that for other grain species or not.

There are several factors affecting nutrient uptake from soil to plants; species, seasons, soil types and soil management plans. When we compare soybean and rice cultivation conditions in Japan, we can see that water management plans are different. For example, soybeans are grown under upland field conditions (the main water supply is rain) and rice plants are grown under waterlogged conditions (continuous water irrigation). Due to their different water management conditions, it is difficult to compare their Cs take-up abilities by simply comparing Cs concentrations in their grains. In this study, therefore, we measured ^{137}Cs concentrations in wild leguminous and non-leguminous herbaceous plants grown on the same sampling ground to compare the take-up ability of Cs from soil. Although the species we observed in this study were different from soybean and rice, ^{137}Cs take-up abilities by different species could be compared because they were grown under the same condition.

2. Materials and methods

2.1. Sampling location

The collection site was on the Chiba Prefecture campus of the National Institute of Radiological Sciences, National Institutes for Quantum and Radiological Science and Technology (QST-NIRS) located about 220 km south from the FDNPP (35.6350° N, 140.1018° E); radionuclide fallout from the nuclear accident had been deposited on the collection site mainly in March to April 2011. The sampling location has been described elsewhere (Tagami and Uchida, 2015). Ishii et al. (2013) reported that the ^{137}Cs fallout amount was about 14.8 kBq m^{-2} on the roof of a five-story building at QST-NIRS near our sample collection site. At the collection site, we obtained three to seven soil core samples (0–5 cm) per year and these data were reported previously (Tagami and Uchida, 2017); the arithmetic mean ^{137}Cs concentration was 12.8 ± 5.2 kBq m^{-2} in 2011–2016, which agreed with the fallout amount of the roof of the building reported by Ishii et al. (2013). The soil type was brown forest soil (pH = 7.1, total carbon content = 3%, K = ca. 8 g kg^{-1}-dry).

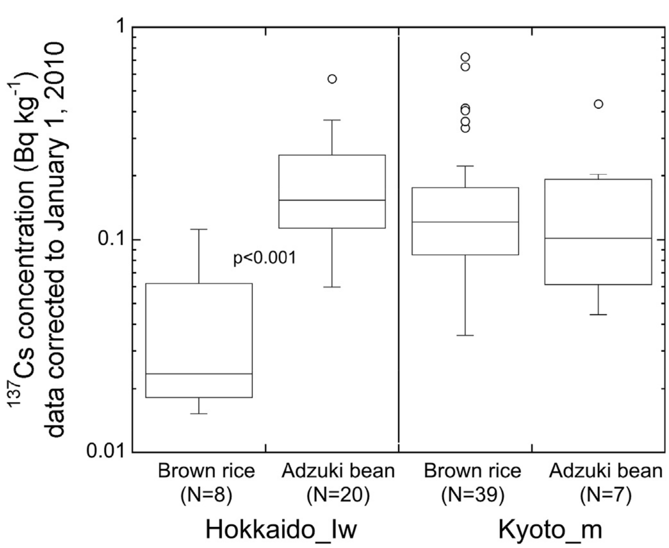

Fig. 1. Global fallout ^{137}Cs activity concentrations in brown rice (*Oryza sativa* subsp. *japonica* Kato) and adzuki bean (*Vigna angularis* (Willd.) Ohwi & H.Ohashi) collected in Iwanai Town in Hokkaido (Hokkaido_Iw) and Maizuru City in Kyoto (Kyoto_m) from 1990 to 2010. Data from NRA (2017) and all ^{137}Cs concentration data were decay-corrected to January 1, 2010.

2.2. Sampling and preparation method

From this site, we collected above-ground parts of the following six species and Poaceae family plants at various times in 2012–2016: two were leguminous species, i.e., red clover (*Trifolium pratense* L.) and narrow-leaved vetch (*Vicia sativa* L.), and the others were non-leguminous, i.e., mugwort (*Artemisia indica* Willd. var. *maximowiczii* (Nakai) H.Hara), field horsetail (*Equisetum arvense* L.), giant butterbur (*Petasites japonicus* (Siebold & Zucc.) Maxim.), knotweed (*Fallopia japonica* (Houtt.) Ronse Decr.), and Poaceae family including several Poaceae family specimens, such as *Eragrostis ferruginea* P.Beauv., *Bromus catharticus* Vahl, and *Paspalum thunbergii* Kunth ex Steud. Hereafter the ^{137}Cs data from the Poaceae family plants were considered as one species. For *E. arvense*, fertile shoots were sampled and for all others, mainly leaves and stems (usually 3–5 cm above the soil surface) were collected. *T. pratense* (Fabaceae family), *A. indica* (Asteraceae family), *E. arvense* (Equisetaceae family), *P. japonicus* (Asteraceae family), *F. japonica* (Polygonaceae family) are perennial plants, *V. sativa* (Fabaceae family) is an annual plant, and Poaceae family plants include both types but mostly perennial plants.

These plants were growing wild on the QST-NIRS ground; no K fertilizer was added. Total numbers of samples for each species were 10–45 throughout the observation period. Immediately after collection, plant samples were transferred to a laboratory and then weighed fresh weight. Except for field horsetail, each tissue was washed with tap water to remove dust from the surface; this was done in a washing bowl by changing the water 5 times, and then, finally, the samples were rinsed with reverse osmosis water. All samples were oven-dried to a constant weight at 80 °C in an electric oven for at least 2 d to decrease the sample volume. After oven-drying, each sample was weighed to calculate its water content. Then the sample was pulverized and mixed well, before being transferred to a 100-mL plastic container. Giant butterbur, knotweed, and field horsetail data were previously studied by separating tissue parts and some data were published (Tagami and Uchida, 2015). In this study, the separated tissue part data were reconstructed to obtain an averaged above-ground datum (^{137}Cs$_{avg}$):

$$^{137}\mathrm{Cs}_{avg}\ (\mathrm{Bq\ kg^{-1}\text{-}dry}) = \sum (^{137}\mathrm{Cs}_p\ [\mathrm{Bq\ kg^{-1}\text{-}dry}]\ M_p\ [\mathrm{g\text{-}dry}]/M_t\ [\mathrm{g\text{-}dry}])$$

where ^{137}Cs$_p$ is the concentration in the plant tissue part, M_p is the dry weight of the tissue part, and M_t is the total weight of the above ground part (sum of all separated tissue parts). We also partially used the ^{137}Cs$_{avg}$ values of giant butterbur, knotweed and mugwort in our previous paper to calculate aggregated transfer factors (Tagami and Uchida, 2017).

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